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ZERO-POWER, INTERACTIVE DOCUMENT VIEWER SYSTEM PROGRAM

by
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Preface

This report outlines research and development activity conducted by Honeywell International Inc., Defense & Space Electronic Systems, Minneapolis, Minnesota, under U.S. Army contract C-DAAN02-98-C-4020, 16 June 1998 to 30 September 2003.

This report describes the design of an ultra-low/no-power, wireless, user-interactive, document viewer. The system features a *zero-power*, pseudo-color, VGA-resolution display (and associated drive electronics) manufactured by Kent Displays, Inc. (KDI). Hence, the viewer is described as the *Zero-Power Display* (ZPD). Honeywell designed and built the remainder of the ZPD system: drive and interface electronics, application software, housing, and user interface.

The report describes a prototype system that demonstrates essential system features using existing components to reduce development cost. Finally, improvements envisioned for a deployable system are discussed.

Acknowledgments

The author wishes to thank Mr. Henry Girolamo of the U.S. Army Soldier Systems Center and Dr. Robert Tulis of DARPA/ATO and Mr. Richard Urban (formerly of DARPA) for sponsoring this work under the DARPA Warfighter Visualization program. The efforts, support, and patience of Jim Sampson, Tom Gilroy, and Mark Chandler (also of Natick SSC) are gratefully acknowledged. Lastly, the assistance of Lyn Snell in assembling this report is deeply appreciated.

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ZERO-POWER, INTERACTIVE DOCUMENT VIEWER SYSTEM PROGRAM

1.0 Introduction

The Zero-Power, Interactive Document Viewer System, or Zero-Power Display (ZPD), program is a Defense Advanced Research Projects Agency (DARPA)-funded research effort contracted through the U.S. Army Soldier Systems Center at Natick, Massachusetts. It was proposed in response to DARPA Broad Agency Announcement (BAA) 97-31, Lightweight Electronic Components for Advanced Protective and Tactical Helmet, Head Mounted, Handheld Body-Worn Systems and Smart Electronic Components/Modules, dated 2 February 1998. A major goal of this BAA was “to fulfill requirements for scientific study and experimentation directed toward advancing the state-of-the-art, or increasing knowledge and understanding as a means of eliminating current technology barriers.” Areas of interest identified in the BAA included: “Research proposals for low weight, low-power, high-efficiency, man-portable systems.” It was further specified that critical areas of interest included an active matrix display, reduced bulk and weight, reduced power requirements, increased pixel resolution, and handheld portability.

The objective of this program is to develop an ultra-low / no-power, wireless, user-interactive, document viewer that could be used by the warfighter to receive, view, store, and send information. The system features a “zero-power,” pseudo-color, VGA-resolution display manufactured by Kent Displays, Inc. (KDI). Honeywell designed and built the remainder of the ZPD system: interface electronics, application software, housing, and user interface.

Once an image has been loaded onto the ZPD’s 133 dpi, *Cholesteric*, Liquid Crystal Display (Ch-LCD) from KDI, the image remains indefinitely without a power source. Hence the viewer will consume power only during the time required to refresh the display.

A key objective of the effort was to create a rugged, waterproof device with a display that can be viewed in starlight conditions using night vision goggles.

In applications with typical daylight ambient lighting, the ZPD is ideal for long-term, high-resolution imagery and text display requiring infrequent updates. For example, a pilot who needs to view flight chart information during the course of a flight would be an ideal application for the ZPD.

The active area of the display is 4.8×3.6 inches. The ZPD’s softkeys surround the display as packaged in its ruggedized, lightweight (<1.25 lb.) housing.

Wired and *wireless*¹ interfaces can be used to send documents to be displayed on the device. The ZPD accepts SmartMedia™ flash memory cards that serve as its memory storage media. An optional PC Card socket and USB port allow the display to connect to other memory storage devices. All of these features plus its reconfigurability (via software download via serial port) combine to produce an autonomous / stand-alone document viewer capable of lasting weeks on a single charge.

Intelligent system power management is maintained by a microcontroller powered by batteries replenished by a solar cell that is integral to the ZPD housing.

In summary, the core features of the ZPD include the following:

- Multiple-color, VGA-resolution, paper-like images that can be read in a broad range of lighting conditions: bright sunlight to starlight (with night vision goggles). The display reflects near-infrared radiation as well as (multi-color) visible light.
- Rugged, waterproof, lightweight (less than 1.25 lb.) unit.
- Capability to read and display JPEG or BMP encoded image files, PDF files, ASCII text files, and documents in HTML format.
- Removable SmartMedia™ memory card for file storage (compatible with digital cameras that use SmartMedia™ cards).
- USB 1.1 interface.
- Wireless (Radio Frequency [RF]) interface.¹
- Touch screen and softkeys for user input and interface.
- Advanced power management plus solar cells for stand-by power and battery recharge.

The purpose of this report is twofold:

1. To chronicle the need for a device such as the ZPD (apparent from its many possible applications) and extract from that need a list of top-level requirements for the ZPD.
2. Provide an overview of the device as it was designed and built by the subject program.

At the end of the report is a brief recommendation regarding the path forward to further develop a device such as the ZPD into a fieldable item, tailored to the needs of the warfighter.

¹ A wireless interface was not implemented in the course of the program.

2.0 Zero Power Display (ZPD) System

This section provides a brief overview of the applications that could be served by a device such as the ZPD. Subsequently, the top-level requirements for a ZPD device are described. It is these top-level requirements that drove the design of the ZPD. A brief synopsis of the ZPD functionality concludes the section.

2.1 Zero Power Display Rationale

2.1.1 Applications and Concept of Operation

Fundamentally the ZPD was conceived as a replacement for hard-copy data of various types:

- Field Manuals (FM)
- Standard Operating Procedures (SOP)
- Maps, flight charts, etc.
- Imagery (reconnaissance – buildings, places, things; photographs of people, etc.)
- Mission instructions (any type of text or graphic required to complete the mission).

In addition, the ZPD should be capable of displaying information previously captured in electronic form:

- Interactive, Electronic Technical Manuals (IETM)
- Information encoded in HTML (Web page) form or PDF
- Pictures in standard formats such as JPEG, BMP, etc.

Maintenance staff could use the ZPD as a small, rugged, IETM reader to provide on-site information. No longer would large, bulky paper manuals be needed. On-site viewing of high-resolution, color-coded schematics, drawings, instructions for repair, etc. would be a major timesaver. The small size, lightweight, and low-power requirement would offer significant advantages over the use of a laptop or a belt-worn computer. This application could use a two-display device (one display for text instructions and one for graphics/schematics, etc.) in a book-like fashion.

A pilot who needs to view flight chart information during the course of a flight would be an ideal application for the ZPD. There would be no need to carry a bulky case of flight charts onto the plane. The utility of the ZPD could be extended to reconnaissance imagery, targeting information, etc. depending upon the aircraft and mission.

A platoon or squad leader needs to view maps with superimposed graphics (troop positions, defensive lines, etc.) and view a variety of field manuals that capture proper procedures to be

followed. The case of field manuals applies to all potential users of the device, from Military Police (MP) and maintenance personnel to front-line troops and Special Forces personnel.

A novel, emerging application is one of language translation. A hand-held display device capable of speech recognition and translation would serve a valuable function across many Department of Defense (DoD) job functions. For example, MPs may encounter situations in which they cannot communicate in the language of local residents. A device such as a ZPD, capable of digitizing speech and translating to English (or converting English into another language) and displaying the result of the speech-to-text conversion for reading purposes, would bridge many communication gaps in the field. This is not a futuristic application. Software is available today (2004) that performs this function on personal data assistants (e.g., PocketPC™ devices). One company in particular that is providing translator software is SpeechGear™.

Perhaps common to all applications are the following improvements that could be offered by the ZPD:

- Improved situational awareness – Quickly provides for viewing and can disseminate information critical to the mission.
 - ✓ Capture information quickly (text or graphic) and transmit it to others. This benefit is realized in the form of recorded imagery, hand-written text, and graphics superimposed on other graphics (maps or images) and then transmitted to others.
- Weight reductions – Weight carried by the warfighter is of serious concern. Increased carried weight typically equates to reduced fightability. Hence, the ZPD must not add to the carried weight, but rather reduce it.
- Light security – Light security is of paramount importance to those on the battlefield. Either there must be no light emission from a display, or the emitted light must be satisfactorily controlled at all times.
- Mission updates – Quick update of the mission-specific information stored as files within the device.

2.1.2 Derived Requirements

In serving the applications specified, the following criteria were defined as requirements:

- Fast access to a large amount of data composed of text, graphics, and pictures.
- Lightweight and pocket-sized.
- Rugged and watertight.
- Very low power requirement (yielding long battery life).
 - ✓ A bistable display to enable low-power operation (liquid crystal material retains its position when power is removed; power is consumed only when display content changes).
 - ✓ Very low-power electronics.

- A large viewing angle to accommodate small group viewing and briefings.
- Display resolution of $\geq 640 \times 480$ (VGA resolution).
- Visible in bright sunlight.
- Light security (no light emissions) for use at night.
- User input via virtual keyboard and stylus entry of sketched graphics and the ability to capture handwritten text.
- Wireless connectivity for data transfer (*planned but not realized*).
- Rapid, mission-specific information download.
- Operation over the full military temperature range (or as much of it as possible).
- Rapid download of information into memory or use of memory card for quick loading of information.

It is this core set of requirements that drove the design of the ZPD. The methods by which the requirements were met are described in the following sections.

2.2 ZPD System Overview

It is the purpose of this section to provide the reader with an overview of the ZPD: its functionality and the benefits of its features.

The most important component of the ZPD is its display, with an active area of 4.8×3.6 inches. Details of the display are provided in section 3.2. Once an image has been loaded onto this 133 dpi, *Cholesteric, Liquid Crystal Display* (Ch-LCD), the image remains indefinitely without a power source. Hence the viewer will consume power only during the time required to refresh the display (currently the refresh rate is limited to <5 Hz for a display having VGA resolution).

The Ch-LCD has no light emissions and, if properly configured, is readable at night using night vision goggles. This capability makes the display very useful for Special Operations applications. In applications with ambient lighting, the ZPD is ideal for long-term, high-resolution, imagery and text display requiring infrequent updates.

All of the physical components of the display are illustrated in Figure 1 and Figure 2.

The ZPD's softkeys surround the display as packaged in its ruggedized, lightweight (<1.25 lb) housing. It is the softkeys that allow the user to control the device and access all of its functionality (see section 3.5 for a description of the graphical user interface).

A touch screen is an integral part of the top cover of the housing. The touch screen is a means of interacting with the user interface, entering graphical overlays onto images and maps, entering text via a virtual keyboard, etc.

The ZPD runs off of four AA batteries stored inside the housing. At the current stage of design, the back of the housing has to be removed to replace the batteries. The battery storage area, being the heaviest region of the ZPD housing, has a hand strap built into the housing to make holding and interacting with the device more secure.

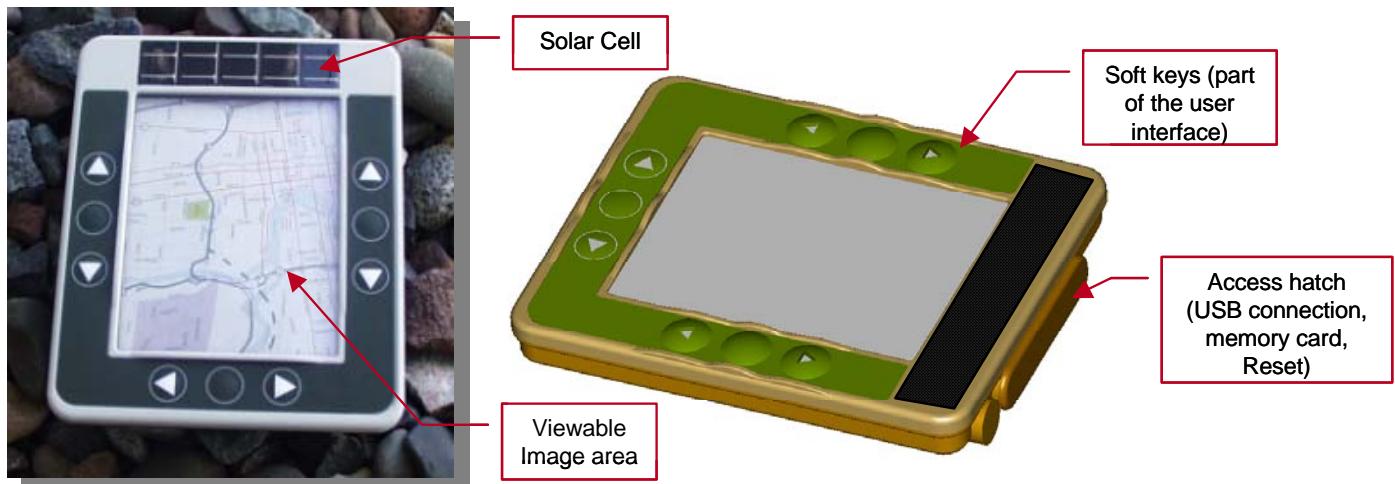


Figure 1. CAD model and photograph of actual ZPD housing (with simulated image).



Figure 2. CAD model of the backside of the ZPD housing showing the battery cavity and hand strap.

Communication and/or file transfer to the ZPD occurs through three distinct means:

- USB 1.1 direct connection
- SmartMedia™ memory card
- Wireless interface – *an RF wireless connection (i.e., Bluetooth) was planned but was not implemented due to the lack of hardware and software driver infrastructure needed during the course of the program. The Bluetooth specification was just forming in the time frame of the program. Actually Bluetooth products only became commercially viable in 2003 – long after the program had been completed.*

Access to the USB and SmartMedia card slot is behind an access hatch covered by a rubberized seal. The ZPD has not been designed as a USB host. Hence a “B” type USB connector is available within the access hatch. A piece of software on a host computer can access all of the ZPD functionality via a USB cable. Files can be downloaded to the memory card, deleted from the card, displayed, etc.

The SmartMedia card slot available within the access hatch requires that a SmartMedia card be inserted fully within its slot before the rubberized seal is put back into place. The ZPD will not operate without a SmartMedia card inserted. The SmartMedia card serves the same function as a “hard drive” in a desktop computer; all files available to the ZPD are stored on the card.

This capability allows the user to load mission-pertinent information, maps and other reference materials composed of text, graphics, and photographs, onto the memory card prior to the mission. All information is then readily available during the mission.

The ZPD device is always powered on, but the intelligent power management software keeps the hardware in a sleep mode awaiting the next command from the user. This is uniquely possible within the ZPD due to the zero power nature of its display.

The ZPD’s reaction to a key press appears instantaneous to the user. The intelligent system power management is maintained by a dedicated microcontroller powered by the charge in a *super* capacitor. The super capacitor’s charge is replenished by the ZPD’s batteries or by a solar cell that is integral to the ZPD housing.

Beyond the bezel-mounted softkeys, the housing incorporates a resistive touch screen to facilitate user interaction with and data input to the ZPD. The design objective was to have the user interface to the ZPD be operable via both the softkeys and the touch screen; hence, the iconic nature of the graphical user interface (see section 3.5). But the touch screen enables a much improved user input capability for the ZPD.

There are two primary means of user input via touch screen:

- Virtual keyboard (used for entering text characters to a file)
- Graphic capture (used for entering freeform lines and handwritten text)
 - ↳ Electronic journal – lets the touch screen function as an electronic notebook
 - ↳ Hand-drawn graphics on top of images and maps – allows the user to annotate images and maps.

3.0 Zero Power Display Design and Development

The purpose of this section is to delve deeper into the details of the ZPD's design and provide some of the history of its development.

First the details of the ZPD's internal architecture are explained. It is this internal electronic architecture that is the fundamental enabler of all of the ZPD's functionality.

Next some of the inherent operational attributes of the Cholesteric LCD used by the ZPD are provided and the details of its use in the ZPD are described.

Thirdly, the mechanical aspects of the design, its graphical user interface, and a host interface are described.

Finally, some of the programmatic details of the program are described and the attempts at demonstrating the ZPD in a realistic user scenario are presented.

3.1 ZPD Architecture

The block diagram contained in Figure 3 represents the top-level architecture of the ZPD. This section describes the major blocks in Figure 3:

- Memory store – SmartMedia™ (required coding of a File Allocation Table) compatible with digital camera format (VGA 640×480 resolution).
- Processor – Intel StrongARM™ (SA-1100).
- IrDA and USB interfaces – These interfaces are incorporated into the processor.
- ChLCD Display Drive electronics – Proprietary electronics designed by Kent Displays Inc.
- Touchscreen controller – Synchronous interface to the SA1100 using its input/output lines. (Also includes audio playback and audio record, but the ZPD has no microphone or speaker at this time.)
- Low-power microcontroller (PIC) – Always on to monitor bezel button presses; powered by a *super* capacitor; recharged by a solar cell or battery.

The SmartMedia memory card serves as the memory store for the ZPD. All data files are stored on the memory card. The PIC processor has its software burned into it and the StrongARM processor's software is burned into the flash memory chips. For storage of data, a file storage format had to be written. It was deemed important to make the memory card files compatible with digital cameras using the SmartMedia card format. Hence, the appropriate File Allocation Table (FAT) system was coded. Therefore, the cards used by the ZPD can be readily used in other SmartMedia card readers, in digital cameras, etc.

- Memory store – Alternate forms of memory card technology could be readily inserted into a future version of the ZPD: Compact Flash, Secure Digital, and PC-Card (which includes functionality beyond simple memory).

The StrongARM processor is used in a wide variety of today's Personal Digital Assistants (PDA) (primarily PocketPC™ devices). A variety of peripheral functions are built into the StrongARM's silicon, e.g., USB interface, IrDA interface, memory controller, general-purpose I/O, etc. It is a very versatile and low-power device in its own right. PDA applications employing the StrongARM achieve low-power operation via system shutdown, in which mode the device is non-operable (e.g., the display is turned off and there is nothing to view). Such systems use a Random-Access Memory (RAM)-based memory store with varying support for memory cards to expand upon the internal RAM. An ARM-based microprocessor would remain to this day as the processor of choice for the ZPD device.

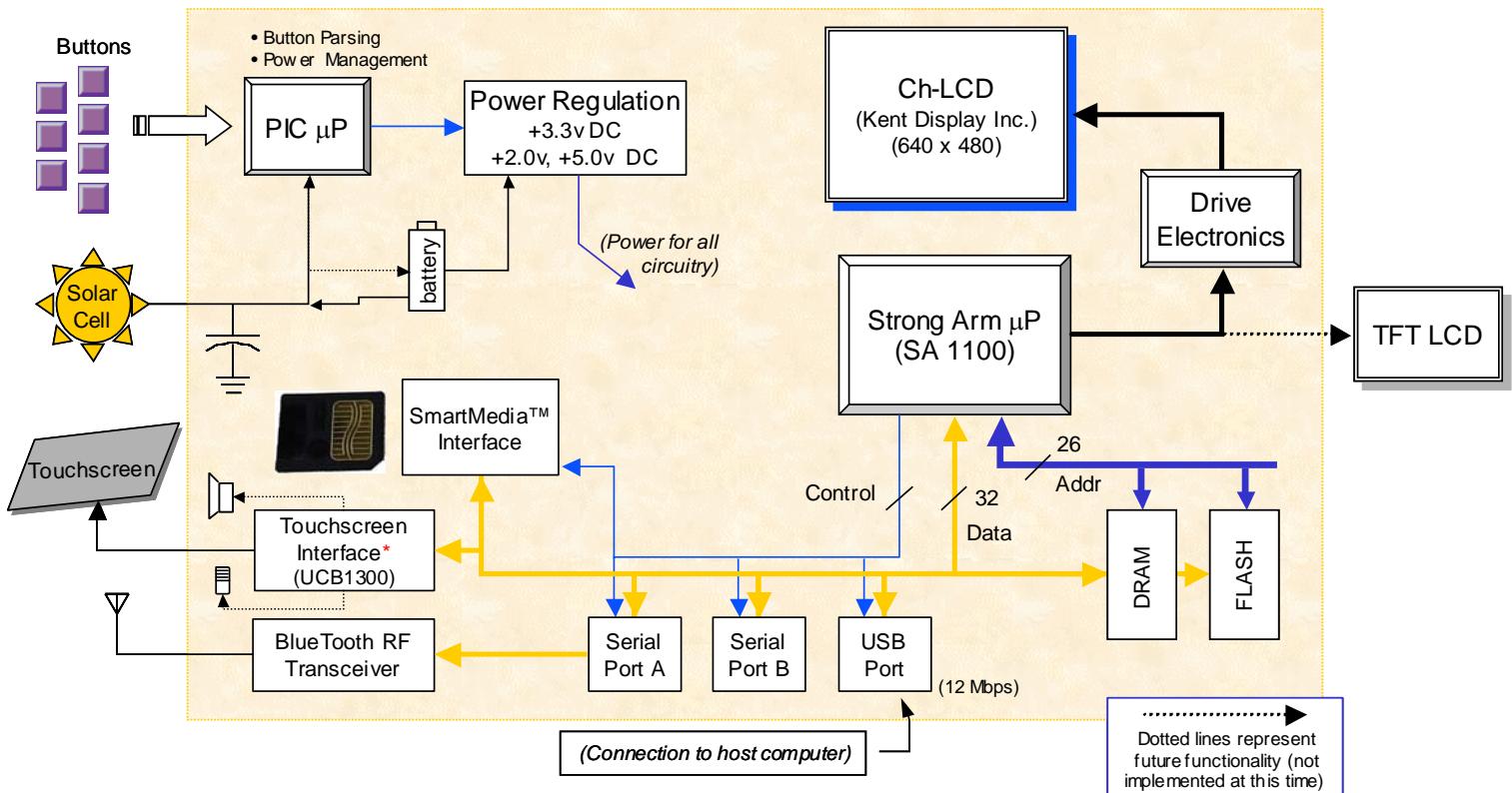


Figure 3. A block diagram representing the architecture internal to the ZPD.

The display drive electronics, consisting of the display drive Application-Specific Integrated Circuits (ASIC) and microcontroller, are proprietary to Kent Displays Inc. The software behind the display drive microcontroller is captured in Programmable Read-Only Memory (PROM). The ASICs that are responsible for driving the display are mounted onto the “tabs”/flex-tapes that provide electrical connection between the ChLCD and the ZPD electronics.

Toward the middle of the program a decision was made to incorporate a four-wire, resistive, touch screen into the ZPD. We selected a product of MicroTouch that fit the available bezel area well and exhibited the highest transmissivity of all available touch screens.

Even though a superb touch screen was chosen, the display brightness is effectively reduced by 20 percent by the touch screen. The Ch-LCD is much brighter and crisper when directly viewed. For this reason a few ZPD devices were built with only a polycarbonate window over the display to maximize brightness and protect the display from ultraviolet radiation.

The Burr Brown chip, ADS7843, met our needs in digitizing the two axes of a 4-wire resistive touch screen. Four general-purpose I/O pins of the SA1110 were programmed to toggle in the appropriate manner to simulate a synchronous serial interface of the type required by the ADS7843 interface.

In order to save Central Processing Unit (CPU) cycles and power consumption, the “15 clock cycles per conversion” interface technique was employed (see Figure 8 in the ADS7843 specification sheet). This is the quickest way to get an x-axis and y-axis sample point out of the BB chip. After the pair is acquired, the BB chip can be put into its sleep mode, to be awakened after the next sample point interval has passed.

- Peripherals built into the touch screen controller include audio playback and audio record. In a future version of the ZPD these peripherals could be employed to implement audio capture, text to speech, speech to text, and language translation functions.

The PIC processor performs the power management for the ZPD. The PIC is always powered on and its power draw is measured in units of μ Amps. The PIC directly controls the state of the power regulators within the system. By shutting off the power regulators, the PIC can shut down all other operations within the ZPD. It is in this manner that the PIC is responsible for the low-power operation of the ZPD. See Section 3.1.1 for additional detail.

- Front lighting is required to view the display at night (if night vision goggles are not an option). “Book light” options would be the most cost-effective solution (relative to internally-mounted “side light” schemes, which would add bulk as well as cost).

3.1.1 Low-Power Electronics

The PIC processor performs the power management for the ZPD. The PIC is always powered on and its power draw is measured in units of μ Amps. The PIC directly controls the state of the power regulators within the system. By shutting off the power regulators, the PIC can shut down all other operations within the ZPD. It is in this manner that the PIC is responsible for the low-power operation of the ZPD.

The PIC itself is interrupted by a press of the softkeys on the bezel of the ZPD. Once the key is decoded, the PIC will enable the power regulators and pass the key press information to the StrongARM processor when it becomes operational. Once the regulators are enabled by the PIC, regulated power becomes available and the Strong ARM “boots.” The user typically sees a result (e.g., the beginning of a screen refresh) within one second.

The PIC will be interrupted when the USB cable power is “sensed” and the unit will go back to “low-power” mode when the cable is removed. While the ZPD is connected to an external host via the USB cable, it will draw power from the host’s USB port to power ZPD operation. This is helpful since the StrongARM processor currently must be powered on in order for commands that arrive over the USB interface to be interpreted and the corresponding action taken.

3.1.2 Data I/O Means

The original design of the ZPD involved three primary means of data input and output to the device:

- Universal Serial Bus (USB) 1.1 interface (primarily a means of transferring files to and from the ZPD)
- Manual memory card insertion
- Wireless, RF, interface

USB 1.1

When the display is static the whole device consumes only the micro amps of power required to “recognize” a USB cable insertion or a softkey push. When the USB is connected, the buttons are ignored. The unit will “wake up” when the USB cable power is “sensed” and the unit will go back to “low-power” mode when the cable is removed. The details of the USB interface to the ZPD are provided in Section 3.3.

Wireless / RF

It was planned that the ZPD would use a *Bluetooth*™ wireless interface. Bluetooth is a short-range wireless networking technology that can pass data at almost 1 megabit per second, with a faster version in development.

The promises of Bluetooth are only now in 2004 coming to fruition. Certain Pocket PC devices from Hewlett-Packard now come standard with Bluetooth, and PC Card format cards are now readily available for laptop (and for suitably equipped desktop) computers. Some examples of tested Bluetooth devices that work are the Socket CF Card, TDK (v1.2.0), 3COM USB Adapter and PC Card, iPAQ 3870, DigiAnswer, and Ambicom CF Card.

Bluetooth is an excellent concept that was over-hyped, and specification issues delayed its technology rollout. Some industry pundits claim that its importance is questionable since 802.11 has been fielded and has become broadly accepted. Also, other technologies such as the next version of USB, IEEE 1394, and ultra-wideband are on the horizon.

During the timeframe of the ZPD program, products had not yet hit the market. It was quite difficult to even obtain prototype transceiver hardware from its manufacturers and the software protocols involved had not yet been fully developed. The Bluetooth specification was in a state of flux.

Today (2004), there are a large number of Bluetooth-enabled devices across the globe, although it still is not clear that the format has gained a solid following. The application Bluetooth was intended to serve (the transparent communication between information devices in a sort of local area network), in this author's opinion, has yet to materialize. Today the technology is confined to printer interfaces, headset wireless links to cellular telephones (the majority of the applications), and other "cable replacement" applications.

Setting aside the differences between the implementations of the various manufacturers and the reported interoperability issues, a Bluetooth implementation is still a challenge.

The bottom line is that Bluetooth has now hit the market in handheld information devices, but it is not clear that it is being widely accepted and used.

The use of Bluetooth within the ZPD was intended to enable two or more ZPDs in proximity to transfer data stored or captured by one user to the others. This is still a good idea, and Bluetooth may yet serve, but ultimately the task was too great for the ZPD program at the time and therefore did not materialize.

3.1.3 Input Means

The ZPD has a limited number of input means through which the user can interact with the ZPD and have the device capture information. This section describes these input means:

- Bezel-mounted soft keys – primarily for interface to the graphical user interface.
- Touch screen – overlaid on the ChLCD.

The bezel buttons are for use in controlling the ZPD via an icon-based, graphical user interface (see section 3.5 for additional detail). The wiring of the softkey assembly is illustrated in Figure 4. Each key is a Single Pole, Single Throw (SPST), momentary contact, dome switch of 12.5

mm diameter. Note that the “center” keys, which serve as *Select* buttons, are all electrically connected such that there are only seven total softkeys.

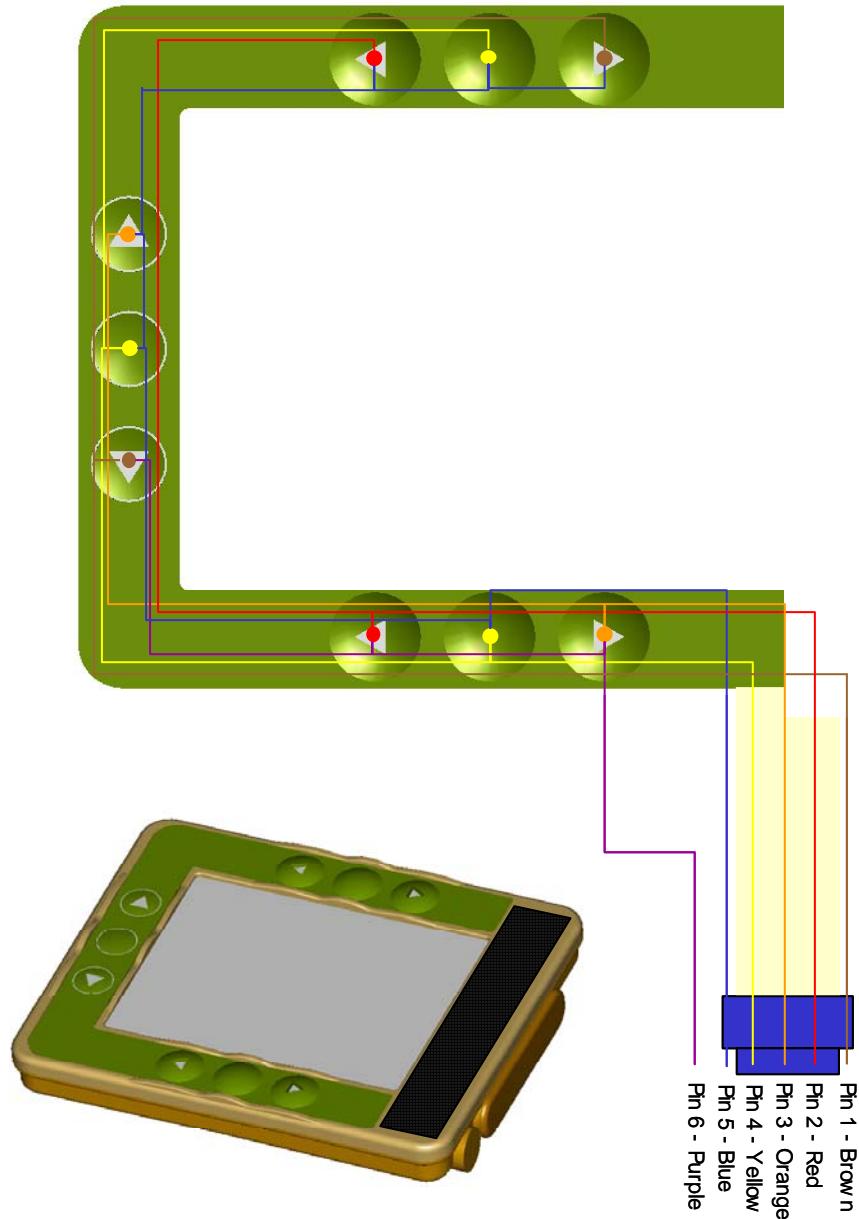


Figure 4. Wiring diagram of the bezel-mounted softkeys.

Next, the applications of a touch screen in devices such as the ZPD are presented. The touch screen is a means of interacting with the graphical user interface:

- *Point-n-touch* selection of items on the display
- Selection of hypertext links within viewed documents
- Selection of menu button.

In addition the touch screen is a means of entering information:

- Electronic journal – handwritten sketches and notes
- Hand-drawn freeform graphics on top of images and maps.

Finally, the touch screen can be used to implement a virtual keyboard that the user can use to enter text into files for later transmittal to others. There exists a near-future capability to implement handwriting recognition (similar to the *Transcriber*TM software currently available for PDAs).

Touch screen benefits:

- Provides intuitive user interface means.
- Turns the ZPD into a multi-function device (display and input device).

Touch screen detractors:

- Decreases display brightness (the touch screen is only ~80% transmissive).
- Increases power consumption (50 mW).
- Increases part count (three chips, oscillator and discretes).

3.2 Cholesteric LCD Technology

Honeywell chose the Cholesteric, Liquid Crystal Display (Ch-LCD) built by Kent Displays, Inc. (KDI) for the ZPD based on its operating characteristics:

1. Low-power operation. Power is consumed only when the display refreshes.
2. Reflective display, viewable in direct sunlight. Peak reflectivity is 40 percent of incident light. High ambient lighting conditions do not degrade the contrast as with typical LCDs, but actually improve contrast.
3. Wide viewing angle (off-angle viewing by as much as 60 degrees from the normal to the plane of the display); permits multiple simultaneous viewers.
4. Additive color display; three image planes are available in a stacked display configuration. The colors employed in the ZPD program are Red, Green, Blue, Yellow, and Infrared.

5. Readable using Night Vision Goggles (NVG). Layers can be tuned to wavelengths visible with NVGs.
6. Very broad operating temperature (0°C to +70°C) and storage temperature (-40°C to +100°C).

The bistable memory of the Ch-LCD allows high-resolution image retention on the display screen for an indefinite time without any applied power. Power is applied only when the display is updated with new content. The energy savings are significant and translate into a practical battery life of 6 to 8 weeks of use, 12 hours a day – an exponential increase over today's most modern displays (see Figure 5).

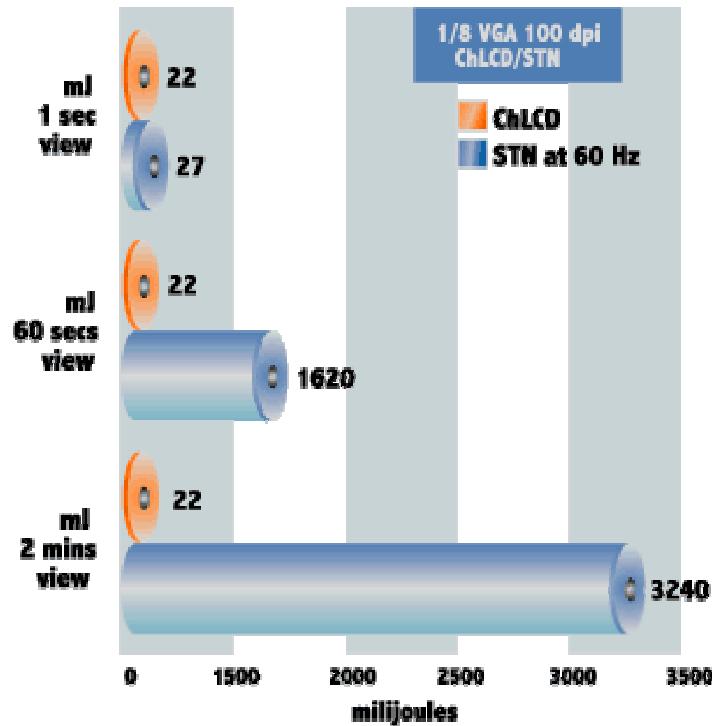


Figure 5. Power usage of LCD technologies used to display a static scene.

The Ch-LCD not only solves battery life issues; it boasts a reflected luminance approaching 40 percent, the brightest reflective display available. The more ambient light there is, the brighter the display will appear.

Due to the wide viewing angle of Ch-LCD, small teams / squads of people can view, and thereby receive, up-to-the-minute information in one briefing – an important feature in all applications. Neither the color nor contrast nor brightness is noticeably altered when read at view angles out to 60° from the normal to the plane of the display.

The Ch-LCD has no light emissions (because it is a reflective display) and is readable at night using night vision goggles due to an optional layer tailored to reflect in the infrared spectrum.

Stacking infrared reflecting displays and visible reflecting displays produces a novel dual-use display module. Due to the optical clarity of the visible display in night vision mode, the two displays are stacked on top of each other without any visual compromise. This display stack has high reflectivity and contrast in both the visible and night vision modes.

There are many types of three-color, stacked displays that can be created with the ChLCD technology. Three combinations in particular were employed during the course of the program:

- [IR /Yellow /Blue]
- [Green /IR /Red]
- [Red /Green /Blue].

In a two-stack display the Blue-Yellow and Red-Blue combinations result in an excellent black-and-white display (when both planes are driven with the same image). This is because the combined spectra (of the two image planes) produce a nearly pure white, i.e., a nearly flat response over the whole of the visible band. This is illustrated in Figure 6, which illustrates a Red-Blue display. As can be seen in the upper left quadrant of the display, when both the Red and Blue image planes are driven identically, the result is a nearly pure white color. The lower right quadrant illustrates the result of neither image plane reflecting any light, resulting in a black color.



Figure 6. An example of a Red-Blue display.

Other combinations, such as the Red-Green display shown in Figure 7, can be created. In this case the brightest color, obtained when both image planes are driven identically (i.e., with the same image) results in a yellow color.

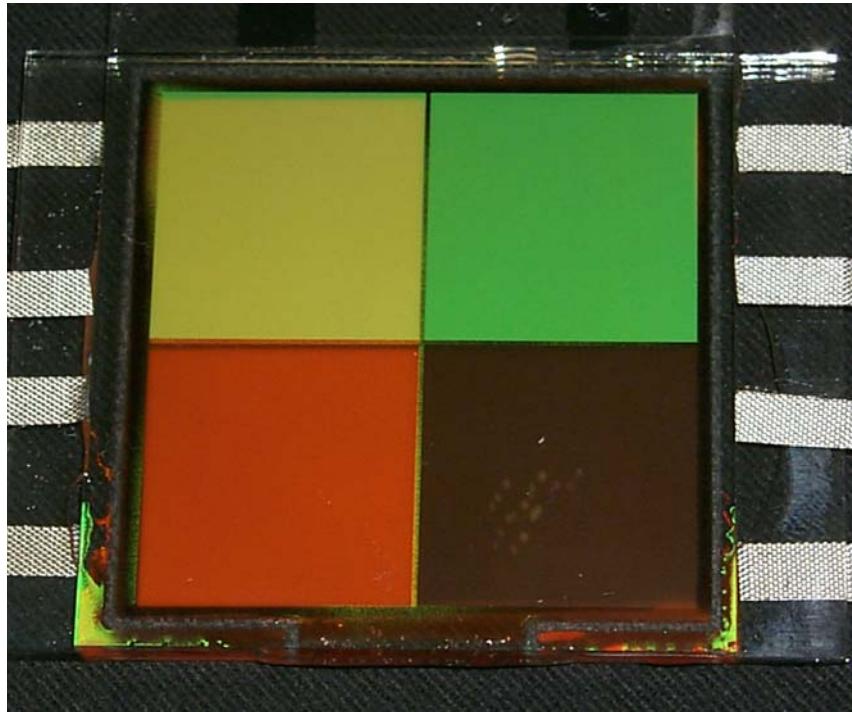


Figure 7. An example of a Red-Green display.

A three-stack display such as Red-Green-Blue will produce the brightest display. This is due to all three image planes reflecting light in the visible spectrum. Basically, the greatest amount of reflected light is generated in this configuration.

The ChLCD capabilities described in this section combine to make the display very useful for Special Operations missions and other applications where activities are conducted at night, long missions where minimal power consumption is crucial (battery weight is minimal) and emitted light might reveal the ZPD user's presence.

KDI, a business unit of Manning Ventures, Inc., is the exclusive worldwide licensee for Kent State University's Ch-LCD technology developed at the Liquid Crystal Institute. The Institute is the world's largest research facility to link basic liquid crystal research to flat panel displays.

3.3 Host Interface

This section describes the means by which a host computer can interact with the ZPD.

Two means of host computer interface were intended for the ZPD:

- USB interface – Provides remote control by a host computer via USB (bi-directional file transfer, display of files, etc.).
- RF wireless interface – A Bluetooth RF wireless interface was intended that would also provide a remote control of the ZPD.

The ZPD is directly controllable via the USB interface. To implement the USB interface on a host computer requires installation of a driver from Microsoft that functions under Windows 2000 and one piece of custom application code.

The ZPD device will “wake up” when the USB cable power is “sensed” and the unit will go back to “low-power” mode when the cable is removed. While the USB cable is connected to the ZPD, the device will stay in its active mode of operation, thereby consuming more power. (Currently the added power comes from the USB host and not from the ZPD batteries). When the USB cable is disconnected, the ZPD will immediately revert to its low-power, standby mode.

The host computer initiates all message transactions with the ZPD. (Note that the ZPD, as a slave USB device, cannot initiate message transactions via the USB interface.)

When the ZPD receives a message, it sends any correctly received message to the appropriate destination function for processing as soon as it has passed the validation check. Messages from the host to the ZPD will require either an *Acknowledge* message or a *Reject* message and in addition may stimulate the ZPD to respond with additional data. The response messages from the ZPD to the host do not require a responding message from the host system.

Each message type has an expected system response(s) and error processing defined. The host shall not retransmit a message or initiate another message to the ZPD unless it has received an *Acknowledge* message or a *Reject* message, or has “timed out” from the previous transmission. The ZPD has no equivalent requirement and may send multiple messages without significant gaps between them.

The USB interface handles all timing concerns regarding message transfer. In addition the USB interface takes care of all error-checking functions. A framing algorithm identifies the beginning of a message in an arbitrary byte stream.

The list of valid message names for the host computer is shown in Table 1, along with Message ID assignments.

Table 1. Valid messages accepted by the ZPD.

Message Name	Message ID	Source	Data Sent (bytes)	Response
View Directory	0xF1	Host	0	Ack/Reject
Change Directory	0xF2	Host	11	Ack/Reject
Make Directory	0xF3	Host	11	Ack/Reject
Remove Directory	0xF4	Host	11	Ack/Reject
Get File	0xF5	Host	11	Ack/Reject
Put File	0xF6	Host	11	Ack/Reject
Delete File	0xF7	Host	11	Ack/Reject
View File	0xF8	Host	11	Ack/Reject
Goto Root Directory	0xF9	Host	0	Ack/Reject
Display Text	0xFA	Host	N	Ack/Reject
Text Mode Off	0xFB	Host	0	Ack/Reject

In response to a received message from the host, the ZPD responds to the host message as follows:

1. If the ZPD determines that the received Message ID byte is valid, then the response from the ZPD is to echo the message ID (one byte).
2. If a valid message ID is not received, the ZPD transmits the complement of the Message ID followed by an Error Code (see Table 2).

In the first case (i.e., the message ID was correct), the host computer can proceed with the message data appropriate to the type of message.

Table 2. Error codes transmitted by the ZPD.

Error Code	Description
0x01	No further description
0x02	Directory does not exist
0x03	File does not exist
0x04	Insufficient space

An interface for a host computer (running Windows 2000) was written. It provides a convenient Windows-based application for transfer of files to and from the SmartMedia card within the ZPD.

3.4 Mechanical Packaging

Early in the design of the ZPD, four different “configurations” for the small display (~6.25 inches diagonal) were contemplated.

There were two fundamental footprints for the display (square vs. rectangular). For each footprint, the device could be used in a landscape or portrait mode. Hence, a total of four configurations were created. The selected design (Figure 1) was rectangular so that the device would fit into a cargo pocket of a typical pair of fatigue pants.

The location of the “tabs”/flex-tapes that surround the active display area drives the external dimensions of the ZPD. There are two kinds of tabs; one much more narrow than the other. The thicker tabs “drive” the rows. Hence, the sides on which the thicker tabs are placed dictate the “rows” of the display. For the rectangular footprint, the narrow tabs are on the thinner dimension. The reverse arrangement would make the footprint of the ZPD more square.

At the kickoff meeting, the decision was made not to invest in any new tab development for cost reasons. Note that tabs could be developed that are curved and/or bendable and therefore reduce the overall footprint of the display device. But such a development was left to a future effort.

Important features of the ZPD housing are its watertight features and the choice of cover “glass” for the ChLCD. Water tightness was achieved by means of an o-ring that lies in a groove on the top lip of the lower portion of the housing. The upper and lower portions of the housing assembly overlap and sandwich the o-ring between them.

It is important to protect the liquid crystal material within the display from UV radiation. Therefore, not just any type of cover “glass” will suffice. Honeywell used Cyro AR1-OP3 from HP Manufacturing. This material was chosen due to its ability to absorb UV radiation, thereby protecting the ChLCD from premature aging.

The weight of the ZPD unit as developed is indicated in Table 3. In a future version of the ZPD, the weight could be significantly reduced. The ZPD components that are eligible for weight reduction are indicated in the table. As one can see, the four AA batteries are nearly 15% of the overall weight of the ZPD in its current incarnation.

Table 3. ZPD Component weight breakdown.

Component	Weight
Back cover *(with battery holder)	201.0 g
Bezel assembly *(with touch screen)	148.5 g
Ch-LCD	162.5 g
Controller PWB *(w SmartMedia)	136.5 g
Batteries (4 AA)	100.0 g
Total	~750 g

* Weight reduction candidate components.

3.5 Graphical User Interface (GUI)

The user metaphor of the ZPD GUI is best described as “up, down, select.” This section describes this GUI.

It was the intent to make the display and its GUI usable regardless of how the device is held: portrait vs. landscape, right hand vs. left hand.

It was also crucial to design the GUI to accommodate a display that is relatively slow in its refresh rate and maximizes the power savings of the ZPD.

For this reason, the row-addressable Ch-LCD interface was implemented. With the ability to refresh only the rows in need of refresh, the system response time to user input, changes in the GUI screen, etc. can all appear to be more in real-time.

The items that follow and their associated figures capture the operation of the GUI:

- The device can be operated either right-handed or left-handed, in either *Portrait* or *Landscape* mode.
- Menu selections will always be displayed at the same physical location on the display (whether in Landscape mode or Portrait mode).
- The *Main* menu has the following selections listed, on the “bottom” lines of the display (the full display shows a list of files that are stored on the SmartMedia card). See Figure 8 for a sample of the menu’s layout.

FILES TOUCH (on) ORIENT BRIGHT

- The display at this menu is showing a list of named files.
 - a. The “*Bottom/Horizontal*” Arrow keys move the user through the menu selections. When the *FILES* List is highlighted, the “*Vertical*” Arrow keys move the user through the list of files.
 - b. When a file in the list is highlighted and the *Select* button is pressed, the ZPD will display the content of that file (the last page viewed, or the title page, if being viewed for the first time).
- When a file is selected/opened, the Menu at the bottom of the screen changes as follows:

PAGE (1): UP / DOWN TITLE FILES ORIENT TOUCH(on) BRIGHT(1)

A sample of the FILE Menu is provided in Figure 9.

Note: For HTML files, pages become defined as they are rendered. It was determined that the best approach was to page back to the Title page of the HTML document.

- If UP/DOWN² is highlighted, pressing the *Down Arrow* button increments the page number (the number being displayed next to the word PAGE, above) for each press of the *Down Arrow* button. If the user then moves to the word TITLE and presses *Select* the Title page is displayed.

Summary of Menu commands from the File Display state:

FILES: Takes the users back to the File listing (that includes the display of available memory on the SmartMedia card).

² UP moves the user to the top or beginning of the document / file, while DOWN moves the user down the document. Thus, DOWN advances only the page number.

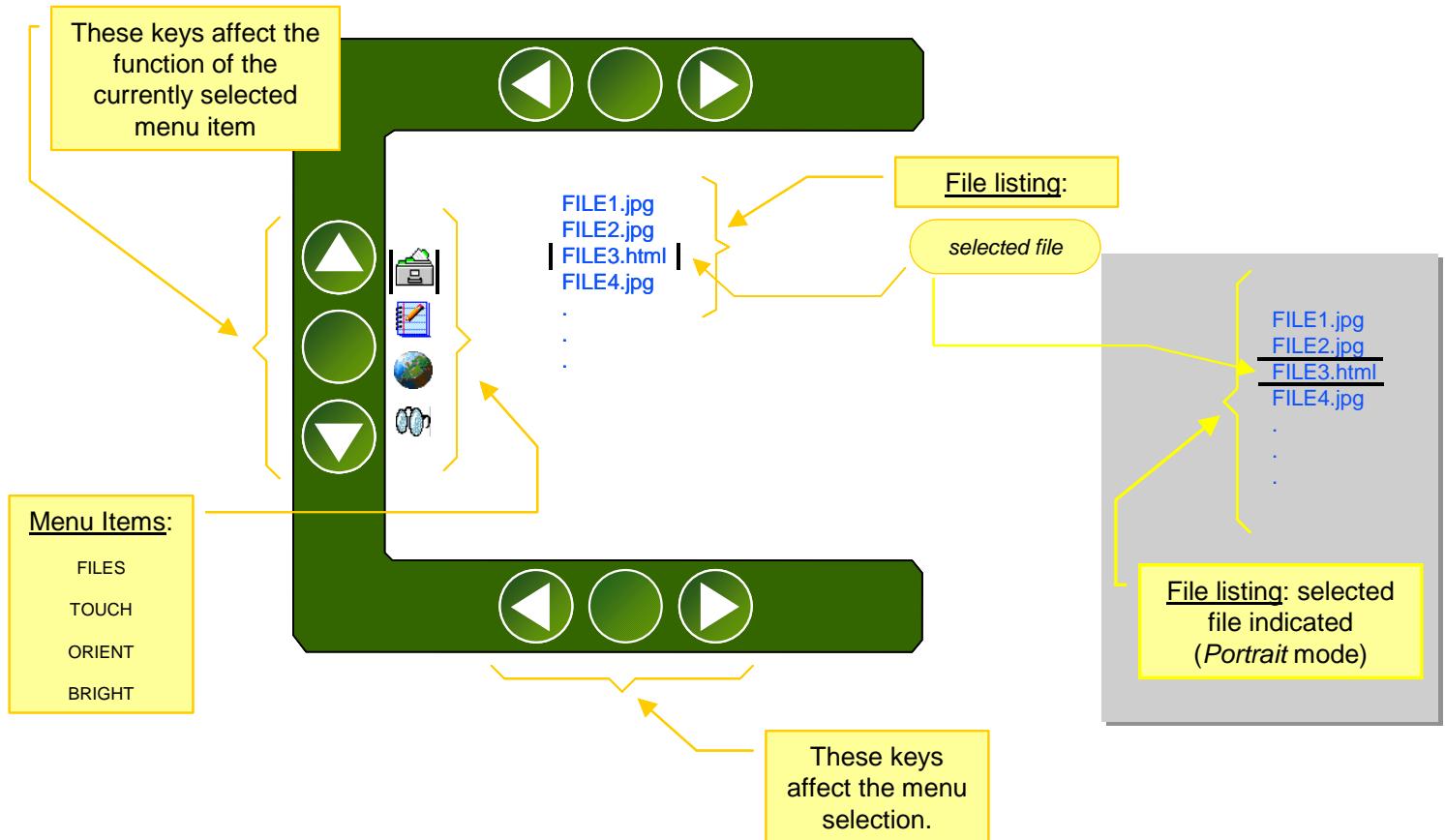


Figure 8. An illustration of the MAIN menu of the ZPD in *Landscape* mode.

ORIENT: Toggling *Select* changes the screen orientation from Portrait to Landscape. While there is only one Portrait orientation, there are two Landscape orientations, one for right-hand operation and one for left-hand operation. Toggling takes the user through these three possible orientations.

TOUCH: Toggles between Touch screen ON, OFF, GRAPHICS, and KEYBOARD. With each push of the Select key, the touch screen mode cycles through the four states.

When the touch screen input mode is selected there are three operational usage options:

- As a means of interfacing to the ZPD's GUI
- As an input means for freehand graphical input (primarily electronic notepad type of input and graphical overlays)
- As a means of text entry via a virtual keyboard.

The TOUCH icon will change its appearance (not its location) when GRAPHICS or KEYBOARD modes are selected.

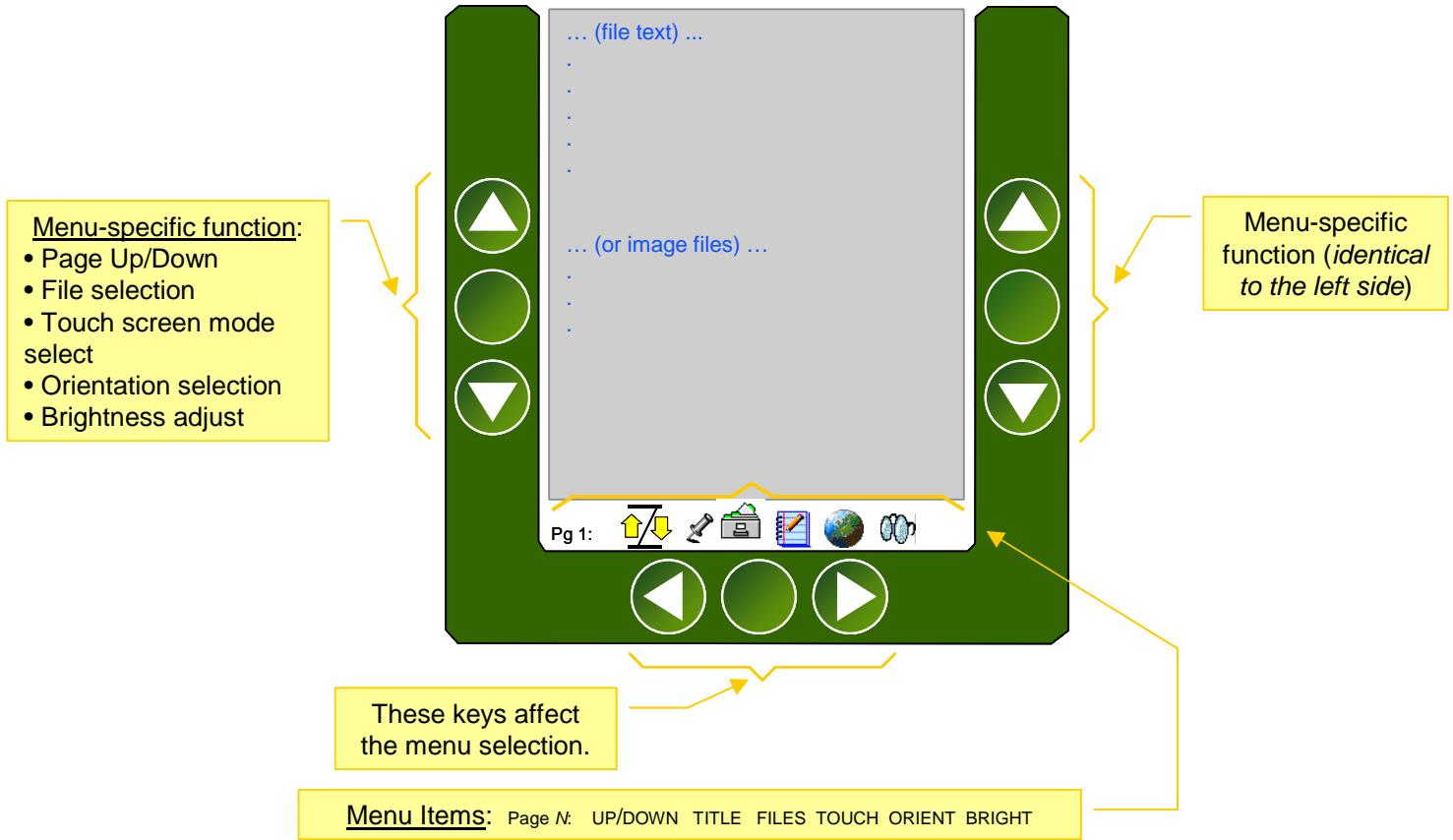


Figure 9. An illustration of the Page View menu of the ZPD's GUI in *Portrait* mode.

When in GRAPHICS mode, all touch screen input is captured in a file with the same name (but different extension) as the viewed file. When using the virtual KEYBOARD, the user is simply entering text into a text file. When the TOUCH function is simply “on,” the touch screen can be used to interact with the device instead of being limited to just the push buttons.

We expect the user to turn on the touch screen when the touch screen is being used and then shut it down when no touch screen activity is required. This is necessary to reduce the power consumption, since the StrongARM processor must be awake to monitor / record touch screen activity.

BRIGHT: When selected by the Menu select buttons, the *Up Arrow* moves the display up in brightness and the *Down Arrow* button decreases the display’s apparent brightness.

Note that there is no option related to a wireless (RF) means of interfacing to the ZPD. A means to select RF operation was designed into the GUI but never implemented.

3.6 Programmatics

The following are the baseline deliverables:

- Two Document Viewers
- One Host Interface Module
- One double stack, night and daylight visible Ch-LCD
- One double stack, enhanced brightness Ch-LCD
- One double stack, black on white Ch-LCD
- System demonstration (option).

January 1999 – As a result of the design review on 1 December 1998 in Minneapolis, a change to the Statement of Work was requested to enable the use of glass displays only. The use of plastic displays was determined to be detrimental to the schedule and otherwise of no technical benefit to the contracted effort.

The wireless link initially contemplated for the ZPD was a Commercial Off-The-Shelf (COTS) RF link or custom (Honeywell) link used in other DARPA-funded programs. The initial approach was replaced due to the desire to incorporate the latest RF link technology known as *Bluetooth*. See Section 3.1.2 for additional information regarding Bluetooth. Leverage with other DARPA efforts involving Bluetooth were anticipated but did not materialize.

A touch screen capability was added in the final six months of the program (for reasons described in Section 3.1.3). When the touch screen activity was added, additional unit deliverables were added.

3.7 Application Demonstration

A decision was made to tie the ZPD demonstrations to those occurring as part of the Digital MP program. An exercise was held at Ft. Leonard Wood in conjunction with the MP school. No in-depth user study was ever realized. This was largely the result of the focus placed on the belt-worn computer and the operation of face recognition software within the Digital MP system. The implementation and test of the computer's interface to the ZPD never received the attention that it required.

As part of the exercise, the ZPD concept was explained to the participants and they were able to hold and view ZPD devices. The feedback from the participants was favorable, but nothing concrete could be determined without the users participating in an actual exercise employing the ZPD. Note that the users did comment that the device was at the limit of acceptable size and they expressed the desire for further volume and weight reductions.

The exercise yielded only a “perceived potential” of the ZPD to the Army MP user jury. This perceived potential, reported relative to other aspects of the Digital MP system, is shown in Figure 10. Certainly future work is required with additional user juries to generate information that would help direct the future development efforts of the ZPD.

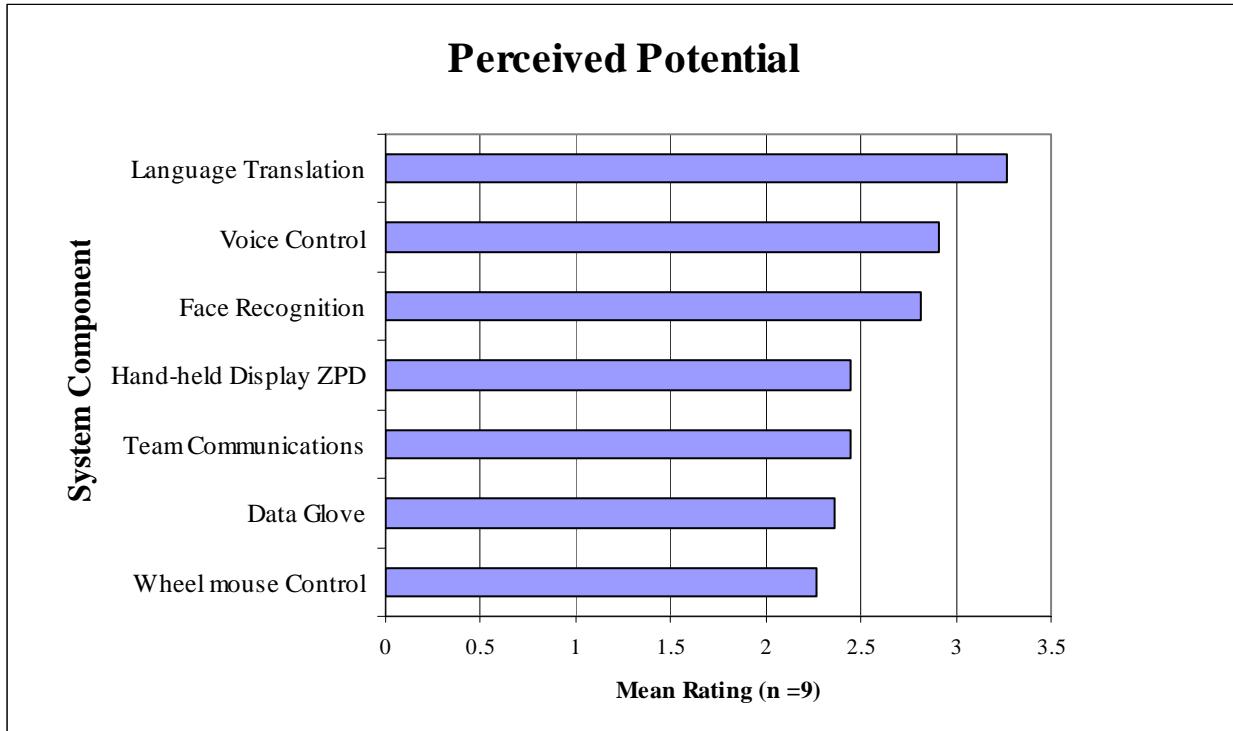


Figure 10. The perceived value of the ZPD relative to the key features of the Digital MP system is shown.

4.0 Summary

The ZPD offers a solution to the problem of battery life of field-deployed information displays. Existing battery packs for field operational displays provide only a few hours of display life. With the ZPD, soldiers located in-theatre can operate for weeks, keeping mission-critical data at their fingertips. The nighttime and daylight readability of the ZPD is significantly better than that of laptops and belt-worn computers, and the unit's resistance to moisture provides an improvement over field-deployed computers.

The ZPD offers the warfighter on the move the capability to view maps, orders, and more. In addition, it is a tremendous fit for Special Operations personnel who operate behind enemy lines with the need to be self-sustaining for weeks without access to additional power sources. The warfighter of the new millennium will increasingly rely on information technology to ensure mission success. The “no-power” attribute of the ZPD provides the warfighter with a logically-friendly and cost-effective link to the digital battlefield. Warfighters can retain access to the information for weeks at a time, yet remain unencumbered by numerous back-up batteries.

The following items capture the highlights of the ZPD design:

- Ideal for long-term, high-resolution, image and text display with infrequent updates—*digital paper*
- Multiple-color, VGA-resolution, paper-like images that can be read in a broad range of lighting conditions: bright sunlight to starlight (with night vision goggles)
- Visible in bright sunlight
- Viewable with night vision goggles
- Rugged, waterproof, and lightweight (less than 1.25 lb.)
- Reads and displays JPEG-encoded image files and documents in HTML format
- Removable SmartMedia™ cartridge for file storage; compatible with digital cameras that use SmartMedia™ cartridges
- USB interface
- Wireless (RF) interface
- Advanced power management plus solar cells for stand-by power and battery recharge
- Weeks of operation on two AA batteries; several thousand page loads.

5.0 Recommendations for Future Efforts

Much of the technology now considered to be a standard part of today's PDAs and tablet computers was not available during the course of the ZPD program. Much of the work done for the ZPD program could be repeated and enhanced now at a much reduced effort and in a much shorter period of time. Hence, it is the purpose of this section to explore the actions that could be pursued to bring a ZPD derivative device to a state ready to be provided to the warfighter.

First of all, the path to a real, fieldable product is through the use of an established operating system such as Windows CE or Embedded Linux. This will enable the display of documents of many types, most notably PDF files. The hardware will support the Windows CE bare requirements with the addition of more flash memory (at least 8MB), which the Printed Wiring Board (PWB) will easily accommodate. Otherwise various options exist for porting the operating system to the hardware platform (vendor tools from Accelent or B-Square, or the basic Platform Builder 3.0 tool from Microsoft). The cost of such of effort is upwards of \$100,000.

In summary, the future plans for fielding a ZPD should include the following considerations:

- Largely COTS platform and toolset (at least all components and drivers are COTS with some unique hardware (e.g., housing, bezel buttons, display drive electronics) and top-level GUI software).
- Compatibility with PocketPC Operating System. The current version, Pocket PC 2002, provides viewing of HTML and full Internet browsing capability. Very inexpensive tools for PDF viewing and PowerPoint file viewing currently exist for this operating system.
- Third-party tools exist to support Intel *StrongARM* and its successor *Xscale* (at one time dictated by Microsoft as the common processor for all PocketPC hardware).
- External battery access, sealed to prevent water entry. Consider use of rechargeable lightweight, high energy density Lithium Ion battery technology. Could implement a means to recharge the battery via the (limited) host power provided via USB port.
- Can readily incorporate CardBus (PC-Card), Compact Flash, or Secure Digital memory card interfaces. These most common interfaces will provide the ZPD with memory storage and/or a variety of additional functionality (RF link, bar code reader, GPS interface, etc.).
- Consolidate electronics – use the latest packaging (BGA and micro BGA packages) and take advantage of recent state-of-the-art electronics miniaturization.

List of Symbols, Abbreviations, and Acronyms

ARM	Acorn Risc Machine (Company Name)
ASIC	Application-Specific Integrated Circuit
BAA	Broad Agency Announcement
CAD	Computer-Aided Design
CF	Compact Flash
Ch-LCD	Cholesteric, Liquid Crystal Display
COTS	Commercial Off-The-Shelf
CPU	Central Processing Unit
DARPA	Defense Advanced Research Projects Agency
DC	Direct Current
DoD	Department of Defense
DRAM	Dynamic Random-Access Memory
EEPROM	Electronically Erasable-Programmable Read-Only Memory
FM	Field Manual
FPGA	Field-Programmable Gate Array
GUI	Graphical User Interface
HMD	Head-Mounted Display
HTML	Hyper Text Markup Language
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
IETM	Interactive, Electronic Technical Manual
FAT	File Allocation Table
IrDA	Infrared Data Association
KDI	Kent Displays Incorporated
MMIC	Monolithic Microwave Integrated Circuit
MP	Military Police
MTO	Microsystems Technology Office (DARPA Office Symbol)
NVG	Night Vision Goggles
PC	Personal Computer
PDA	Personal Digital Assistant
PIC	Microprocessor Company Name (PIC)
PROM	Programmable Read-Only Memory
PWB	Printed Wiring Board

RF	Radio Frequency
SOP	Standard Operating Procedure
SPST	Single Pole, Single Throw
TDK	Technical Development Kit
TS	Touch Screen
USB	Universal Serial Bus
V	Volt
VGA	Video Graphics Array
ZPD	Zero Power Display